Geoacoustic Inversion in Shallow Water

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LONG TERM GOALS

The ability to predict the sound field in shallow water is constrained by the knowledge of the geoacoustic properties of the bottom. The long term objectives of this research project are related to the investigation of experimental methods and inversion techniques for estimating parameters of geoacoustic models of the ocean bottom and the associated uncertainties in the model parameter values. The specific goals are to evaluate the performance of geoacoustic inversion techniques that have been developed for use in range-dependent shallow water environments, and synthesize the results obtained for characterizing the seabed from the SW06 and other recent experiments. The wider context of this research is to achieve improved sonar system performance through greater understanding of the physics of the interaction of sound with the ocean bottom.

OBJECTIVES

There are two objectives in this research report. The first is to compare the performance of geoacoustic inversion methods that have been developed for estimating geoacoustic models from acoustic field data. The inversion performance has been assessed previously in ONR Benchmarking workshops (Tolstoy et al., 1998; Chapman et al., 2003) that used simulated acoustic fields for several candidate shallow water waveguide environments. The hypothesis in this work is that data from the ONR SW06 experiment can serve as an experimental benchmark for assessing inversion performance against real data. This report compares the performance of geoacoustic inversion methods that were used to estimate parameters of geoacoustic profiles in SW06. These include matched field inversion, reflection coefficient and bottom loss inversion, and wavenumber extraction inversion.

A critical issue in the many of the inversion methods is the impact of uncertainty in the knowledge of the ocean environment and the experimental geometry on inversion performance. A second objective in this work is to investigate approaches for estimating geoacoustic model parameters that are robust to environmental and experimental uncertainty.

APPROACH

The research makes use of data recorded from different experiments in the vicinity of the MORAY site shown in Figure 1 (Yang et al., 2008). This area of outer shelf wedge sediments (Goff et al., 2004)

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was intensively surveyed with chirp sonar, in situ seabed physical property measurements, and sediment cores and grab samples. Two hydrophone arrays were deployed at the site, first the MORAY vertical array system from the Applied Physical Laboratory (APL), and subsequently a Marine Physical Laboratory (MPL) vertical array (VLA1), so that there are high quality data covering the full frequency band from 50 Hz to 20 kHz. Also the Woods Hole SHARK vertical array was deployed nearby. The experiments were carried out at close ranges (< 200 m) from the arrays, and along tracks out to 8-10 km.

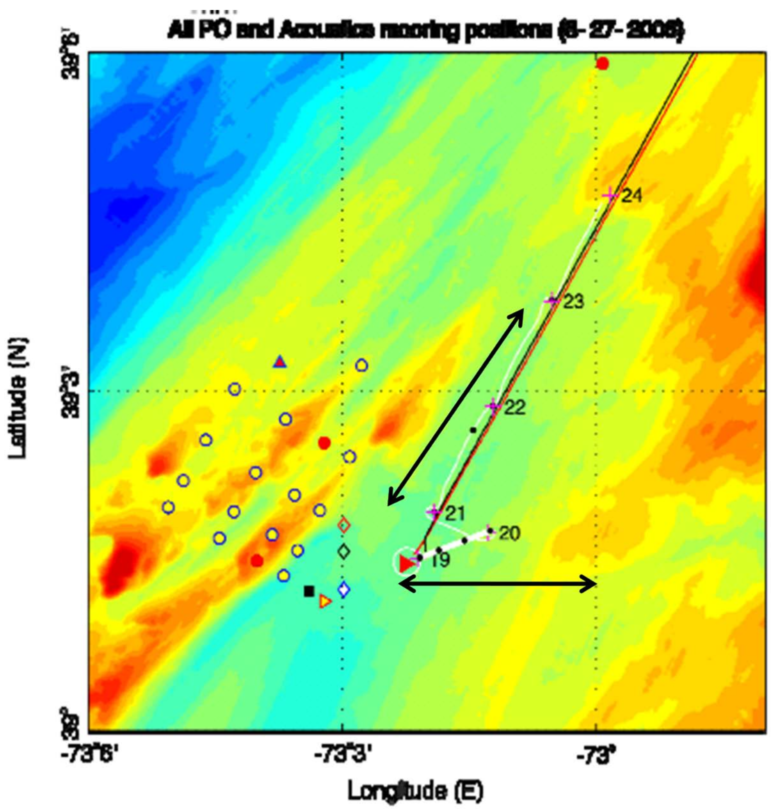

Figure 1. Location of the experiments on the New Jersey Shelf. The red triangle is the MORAY/MPL array site and the white diamond is the SHARK array site. The red line follows the track of the MFI experiments, and the black line nearly parallel to it follows the track of the wavenumber inversion experiment. The DRDC-A track is follows the latter track.

The high resolution chirp sonar surveys revealed well-resolved sub-bottom structure down to about 30 m, most prominently the 'R' reflector at about 20 m (Goff et al., 2004). This interface, which is pervasive in the region, was overlaid with alternating layers of sand and finer clay. The preliminary analysis of the situ sediment probe data indicated a sound speed value of around 1620 m/s for the sea floor sediments near VLA1 (Yang et al., 2008).

The comparison of inversion performance involves several steps. Previously, the geoacoustic estimates from the different inversion methods were compared. The comparisons of estimates of

sediment sound speed and attenuation demonstrated the consistency of the results from different techniques, and showed the accuracy with respect to ground truth information (Chapman, 2012).

The approach described here assesses the inversion performance by comparing predictions of transmission loss (TL) versus range calculated for each inverted profile. Inter-model predictions are compared over the frequency range from 100 Hz to 400 Hz, which was the same frequency band of the data that were used in the low-frequency inversions. Model predictions are then compared with experimental data obtained by the Defence Research and Development Canada-Atlantic (DRDC-A) along a track through the MORAY site (Pecknold, 2008). These data for a sound frequency of 1200 Hz provide experimental results outside the band of frequencies that were used in the inversions. This provides a means to test the robustness of the inverted models over a wider frequency band. Other metrics such as signal coherence or TL versus depth for example, were considered for more comprehensive comparisons that involve determining the sensitivity of the model parameters.

WORK COMPLETED

The inter-model comparisons and the comparison with measured transmission loss were carried out using the geoacoustic profiles that were reported for each of the inversion methods that were tested:

- Waveform and bottom loss matching (Choi et al. 2008)
- Matched field inversion (Jiang and Chapman, 2008; 2009)
- Matched field inversion (Huang et al., 2008)
- Wavenumber extraction inversion (Ballard et al., 2010).

The first method used data from the mid-frequency band (2-6 kHz), whereas the other three used low frequency data in the band 50-700 Hz). These methods were selected because they used data exclusively from the vicinity of the MORAY site where the ground truth was very well established.

The model predictions were done using the normal mode method (ORCA), assuming a range-independent profile. This was a reasonable assumption given that the bathymetry was slowly varying over a large area in the vicinity of the site, and along the experimental track (less than 3 m over 12 km, Pecknold et al., 2008).

A technique that shows considerable promise for robust inversion with limited knowledge of the experimental environment is time-frequency warping. Warping involves transforming the modal dispersion relationship to a new time-frequency domain where the modes are represented as tones near the cut-off frequency. This method was implemented and tested using light bulb data recorded on the MPL vertical array (Bonnel et al., 2012).

RESULTS

The basic characteristics of the four geoacoustic models are represented in Figure 2 that shows the estimated sound speed profiles for the sediment layer. The main features that are likely to affect the predictions of transmission loss are the average sound speed in the layer and the layer thickness.

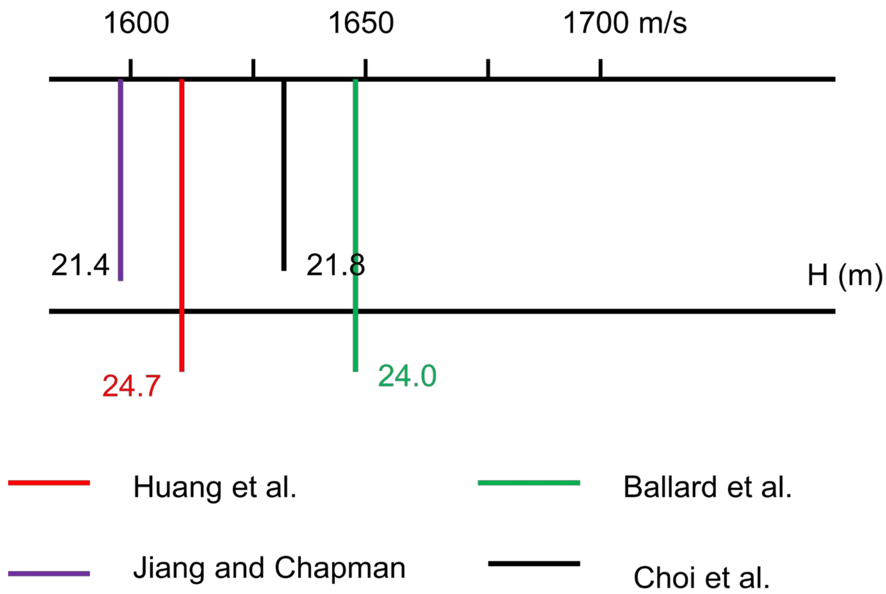

Figure 2. Comparison of average sound speed estimates. The depth to the 'R' reflector is shown (in m) for each inversion method.

Inter-model comparisons of TL are shown in Figures 3 and 4 for 100 and 400 Hz, respectively. Overall, the predictions of TL versus range from all the different models are very close. The comparison at 100 Hz shows the impact of the different estimates of the layer thickness in the different modulations in the TL with range. The higher (400 Hz) frequency is less sensitive to the interface at the bottom of the layer, and is likely more affected by the sediment sound speed and attenuation. The estimated sound speeds varied from 1600-1650 m/s (Figure 2), and values of attenuation used in the model predictions varied from 0.05 dB/λ (Choi et al.) to 0.5 dB/λ (Ballard et al.) However, the predicted TL is very close for all the models, suggesting that there is little sensitivity to these parameters over the relatively short range out to 15 km. However, it should be noted that attenuation was not estimated in some of the inversions and nominal values were used in inferring the profiles.

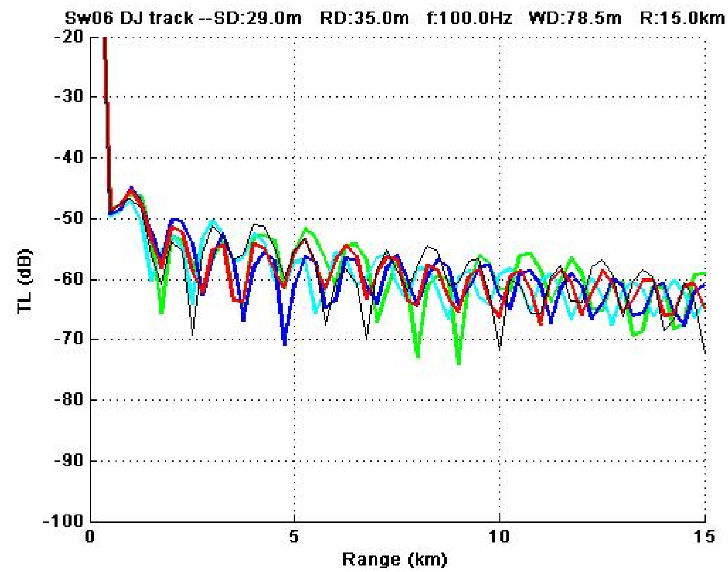

Figure 3. Comparison of predicted TL at 100 Hz. Legend: black: Nominal model pre_SW06; red: Jiang and Chapman; blue: Huang et al.; cyan: Ballard et al.; green: Choi et al.

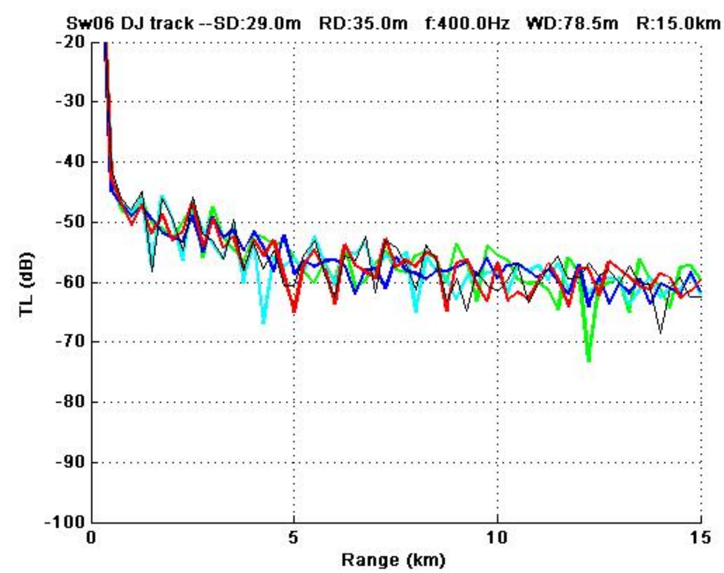

Figure 4. Comparison of predicted TL at 400 Hz. Legend: black: Nominal model pre_SW06; red: Jiang and Chapman; blue: Huang et al.; cyan: Ballard et al.; green: Choi et al.

A more useful assessment of the inversion performance is obtained from comparison with the experimental TL data at 1200 Hz (Figure 5). At this higher frequency, the impact of the sediment sound speed at the sea bottom (or in these cases the average sound speed in the sediment) and the attenuation are expected to have the greatest impact on the predicted TL. Overall the agreement with

the data is very good out to about 7-8 km, and all the model predictions are in close agreement with each other over the entire range. The differences with the experimental data at longer ranges may be due to the use of the range-independent assumption in the TL calculations.

These results suggest that the different inversion methods are capable of estimating a geoacoustic profile that is adequate and robust over a wide frequency range. The sensitivity to the estimated sediment sound speed does not appear to be significant over the spread of values from the different models. However, the sensitivity to estimated attenuation is not conclusive from these results, and further assessment requires data from longer ranges. It is worth noting that the estimated values of attenuation for the outer shelf wedge sediments that were reported from SW06 experiments (Jiang and Chapman, 2010; Turgut, 2009) are lower compared to the higher attenuation reported by Zhou (2009) for the sandy sediments in most of the New Jersey shelf. The reason for this discrepancy is under investigation.

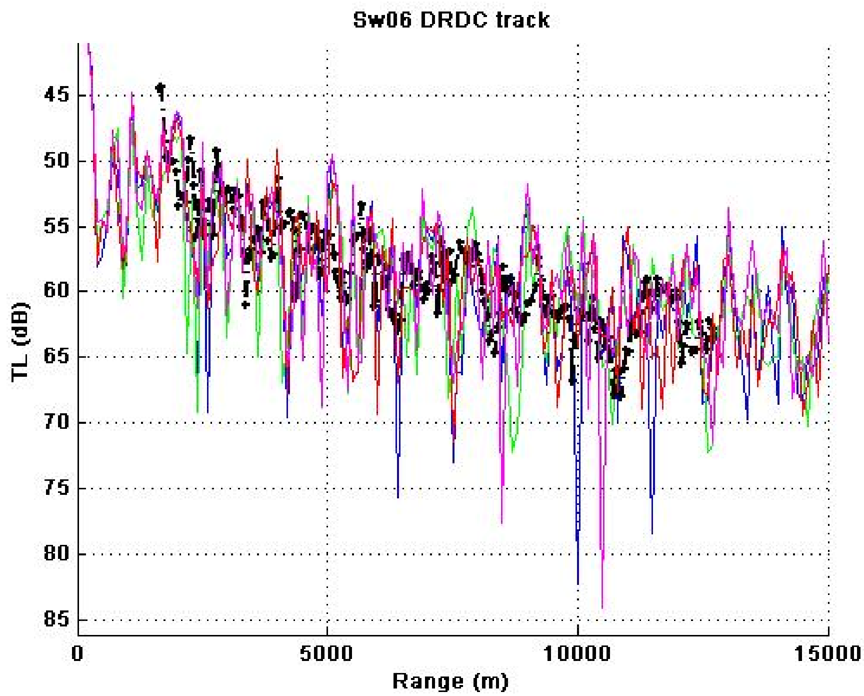

Figure 5. Comparison of predicted TL with experimental data at 1200 Hz. Legend: black: DRDC-A data; red: Jiang and Chapman; blue: Huang et al.; cyan: Ballard et al.; green: Choi et al.

Attenuation can also be inferred from modal amplitude ratios at long ranges. However, this method relies on high resolution of the modes, which is generally possible only for long range data. This method is being investigated in relationship to the time-frequency warping method to take advantage of the improved resolution provided by time-frequency warping at considerably shorter ranges. Initial results with the time-frequency warping method were reported for estimation of sediment sound speed and density from light bulb data recorded on the MPL array (Bonnel and Chapman, 2011). The significant advantages of this technique are the improved modal resolution at relatively short ranges and the insensitivity to uncertainty in knowledge of the experimental environment. Sediment sound speed estimated from a light bulb implosion at ~ 7 km (1600 m/s) was consistent with the values from the other inversions at the site. Additionally, the density is also obtained in the inversion.

MPACT/APPLICATIONS/TRANSITIONS

The assessment of performance of the inversion techniques will provide new information about the limitations and advantages of the different methods. The improved understanding of inversion performance will guide the design of the next stage of ONR experiments to estimate geoacoustic profiles and in particular the attenuation in marine sediments at low frequencies.

RELATED RESEARCH

The data from the SW06 experiments are high quality data that can serve as benchmark standards for evaluating the performance of geoacoustic inversion methods to provide new understanding of the strengths and limitations of present day inversion techniques. The knowledge gained in this work will identify gaps in our understanding that can be addressed in designing the next phase of experiments. The research is connected with research projects of the following: W. S. Hodgkiss and P. Gerstoft (MPL, SCRIPPS); D. Knobles (ARL:UT); G.V. Frisk (Florida Atlantic); K. Becker (ARL Penn State); P. Dahl and D.J. Tang (APL UW); J. Miller and Gopu Potty (University of Rhode Island), J. Goff (U of Texas at Austin) and J. Lynch (WHOI). The overall goal of this group is to characterize the geoacoustic environment and understand mechanisms of the interaction of sound with the ocean bottom.

Another site in the SW06 experiment that was characterized by a top layer of medium sand was studied by several of the PIs. This site was also surveyed extensively for ground truth, and can serve as another benchmark site.

REFERENCES

Ballard, M.S., K. Becker and J.A. Goff, Geoacoustic inversion for the New Jersey Shelf: 3-D sediment model, IEEE J. Oceanic Eng., 35, 28-42, (2010).

Chapman, N.R., S.A. Chin-Bing, D. King and R. Evans, 2003. Benchmarking geoacoustic inversion methods for range dependent waveguides. IEEE J. Oceanic Eng. 28, 320–330.

Chapman, N.R., Assessment of geoacoustic inversion methods, J. Acoust. Soc. Am. 131, 3240 (2012)

Choi, J.W., P. Dahl and J. A. Goff, Observations of R-reflector and sediment interface reflection at the Shallow Water '06 central site, J. Acoust. Soc. Am., 124, EL128-EL134, (2008).

Goff, J.A., B.J. Kraft, L.A. Mayer, S. G. Schock, et al., Seabed characterization on the New Jersey middle and outer shelf: correlation and spatial variability of seafloor sediment properties, Marine Geology, 209, 147-172, (2004).

Huang, C-F, P. Gerstoft and W.S. Hodgkiss, Effect of ocean sound speed uncertainty on matched-field geoacoustic inversion, J. Acoust. Soc. Am., 123, EL162-EL168, (2008).

Jiang, Y. and N.R. Chapman, Bayesian Geoacoustic Inversion in a Dynamic Shallow Water Environment, J. Acoust. Soc. Am. 123, EL155, (2008).

Pecknold, Sean P., Kiyoshi W. Masui, and Paul C. Hines, Transmission loss measurements and geoacoustic sensitivity modeling at 1.2 kHz, J. Acoust. Soc. Am., 124, EL110-EL115, (2008).

Tolstoy, A., N.R. Chapman and G. Brooke, Workshop '97: Benchmarking for Geoacoustic Inversion in Shallow Water, J. Comp. Acoustics, 6, 1–28 (1998).

Turgut, A., Wide band attenuation measurements in New Jersey Shelf sediments, J. Acoust. Soc. Am. **124**, 2468 (2008).

Yang, J., Dajun Tang, and Kevin L. Williams, Direct measurement of sediment sound speed in Shallow Water '06, J. Acoust. Soc. Am., 124, EL116-EL121, (2008).

Zhou, J.X., Low frequency geoacoustic model for the effective properties of sandy sediments, J. Acoust. Soc. Am. 125, 2847-2866, (2009).

PUBLICATIONS

Jiang, Y. and N.R. Chapman, Bayesian Geoacoustic Inversion in a Dynamic Shallow Water Environment, J. Acoust. Soc. Am. 123, EL155, (2008).

Jiang, Y-M, N. Ross Chapman and P. Gerstoft, Short range travel time geoacoustic inversion with vertical line array, J. Acoust. Soc. Am. 124, EL135, (2008).

Jiang, Y. and N.R. Chapman. The Impact of Ocean Sound Speed Variability on the Uncertainty of Geoacoustic Parameter Estimates, J. Acoust. Soc. Am. 125 2881 (2009)

Jiang, Y-M, N. Ross Chapman and P. Gerstoft, Estimation of geoacoustic properties of marine sediment using a differential evolution inversion method, IEEE J. Oceanic Eng. 35, 59-69, (2010).

Jiang, Y-M and N. Ross Chapman, Measurement of low frequency sound attenuation in marine sediment, IEEE J. Oceanic Eng. 35, 70-78, (2010).

Bonnel, J. and N. Ross Chapman, Geoacoustic inversion in a dispersive waveguide using warping operators, JASA Express Letters, EL101-EL107, 2011.